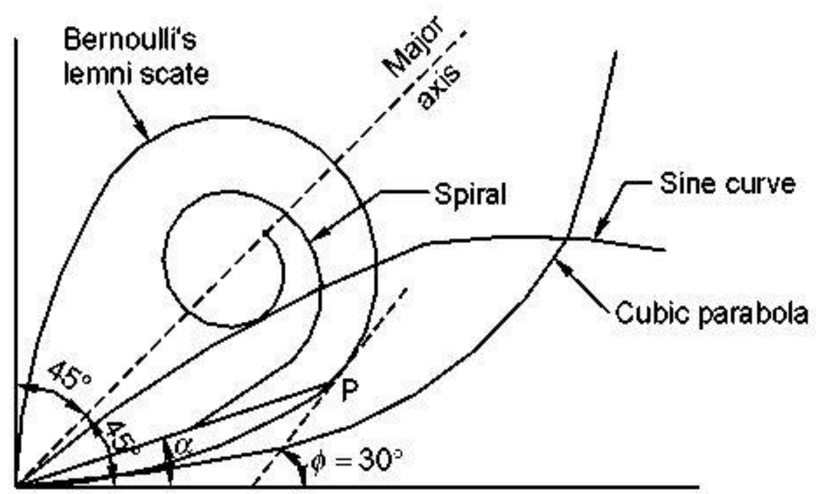
UNIT-II

GEOMETRIC DESIGN OF HIGHWAYS

1. Differentiate between Right of Way and Carriage way (NOV/DEC 2019)

Right of Way	Carriageway
Right of way is the area of land acquired for the road along its alignment. The width of this acquired land is known as land width and it depends on the importance of the road and possible future development.	The pavement or carriageway width depends on the width of traffic lane and number of lanes. The carriage way intended for one line of traffic movement may be called a traffic lane. Keeping all these in view a width of 3.75m is considered desirable for a road having single lane for vehicles of maximum width 2.44m. For pavements having two or more lanes, width of 3.5m per lane is considered sufficient

2. Draw a typical Transition curve and mark all its zones (NOV/DEC 2019)



3. What are the fundamental principles of alignment? (April/May 2019)

- Design speed
- Sight distance
- Horizontal curves
- Drainage gradient
- Super elevation

4. **What are the type of sight distance? (April/May 2019), (Nov/Dec 2016)**

Sight distance available from a point is the actual distance along the road surface, over which a driver from a specified height above the carriage way has visibility of stationary or moving objects.
Three sight distance situations are considered for design:
• Stopping sight distance (SSD) or the absolute minimum sight distance
• Intermediate sight distance (ISD) is defined as twice SSD
• Overtaking sight distance (OSD) for safe overtaking operation
• Head light sight distance is the distance visible to a driver during night driving under the illumination of head lights
• Safe sight distance to enter into an intersection.

5. **What is meant by widening of pavement on horizontal curves? (April/May 2018), (May/June 2016)**

Extra widening refers to the additional width of carriageway that is required on a curved section of a road over and above that required on a straight alignment. This widening is done due to two reasons: the first and most important is the additional width required for a vehicle taking a horizontal curve and the second is due to the tendency of the drivers to ply away from the edge of the carriageway as they drive on a curve.

6. **What is the maximum and Minimum super -elevation?(April/May 2017)**

Depends on (a) slow moving vehicle and (b) heavy loaded trucks with high CG.
IRC specifies a maximum super-elevation of 7 percent for plain and rolling terrain, while that of hilly terrain is 10 percent and urban road is 4 percent.

The minimum super elevation is 2-4 percent for drainage purpose, especially for large radius of the horizontal curve.

7. **Define camber. (April/May 2017)**

Camber, also called as cross fall, is the convexity provided to the cross section of the surface of carriage way. It is the difference in level between the highest point, known as the crown usually located at the centre of the carriage, and the edge.

Camber is provided so as

To drain surface water
To separate the traffic in two opposite directions
To improve the appearance of the road

8. **What are the elements involved in Highway geometric design? (May/June 2016)**

Geometric design of highways deals with:

i. Cross section elements

ii. Sight distance considerations

iii. Horizontal alignment details

iv. Vertical alignment details

v. Intersection elements.

9. Briefly explain illumination sight distance. (April/May 2015)

This is the distance visible to the driver during night driving under the illumination of the vehicle head lights. This sight distance is critical at up gradient and at the ascending stretch of the valley curves.

10. Define sag curves (April/May 2015)

Sag vertical curves are curves that connect descending grades, forming a bowl or a sag. Designing them is is very similar to the design of crest vertical curves.

11. What are overtaking zones? (APR/MAY 17)

The intervals or zones on the highways provided for the purpose of safety overtaking operation of fast moving vehicles with slow moving vehicles, without any collision of vehicles from opposite side are called overtaking zones.

12. What are the types of curves in highway geometric design and write any two salient features of any one curve?(Nov/Dec 2018)

I. Horizontal curve

a) Simple curve
b) Compound curve
c) Reverse curve
d) Transition curve

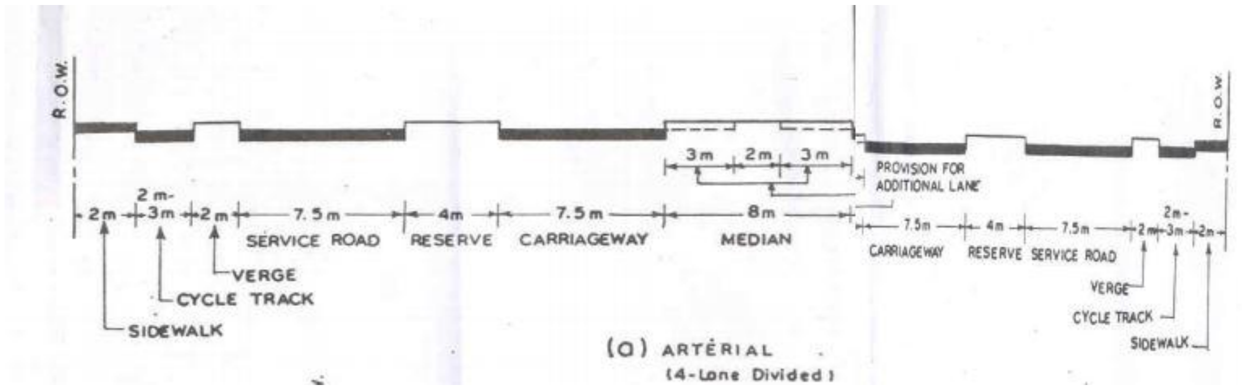
II. Vertical curve

a) Sag curve
b) Summit curve

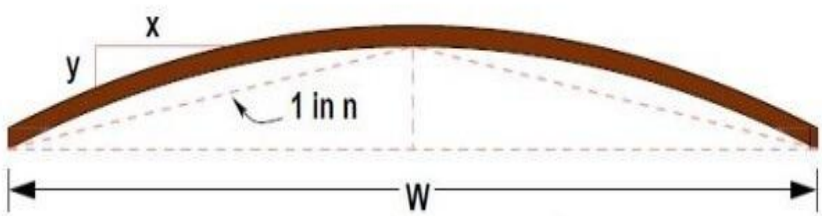
<u>Salient Features of summit sag curve</u>

a) Safety and
b) Comfort travelling between gradients

13. With neat sketches show the typical cross section of any one urban road as per Indian Road Congress (IRC) standards. (Nov/Dec 2018)



14. State the marit and demerit of parabolic camber (Nov/Dec 2017)



Parabolic camber $y=2x^2/nw$

Marit	Demerit
Camber provides quick drainage of rainwater and thus saves the foundation course of the road structure from weakening by percolation of rainwater to it through the road surface.	The roads will wear and tear on the edges. The passengers feel unbalance and discomfort during journey
This prevents rainwater to accumulate in local shrinkages or depressions and forming water pool on the road surface, which are disagreeable to the public as well as to the road structure.	It reduces the road width as everyone will try to move on the middle of the road.

15. Find super elevation on a horizontal circular curve of 150 m radius for design speed of 65Kmph with a coefficient of friction 0.15. (Nov/Dec 2017)

Solution:

$$\boxed{\therefore e + f = \frac{V^2}{127R}}$$

$$e + 0.15 = \frac{(65)^2}{127(150)}$$

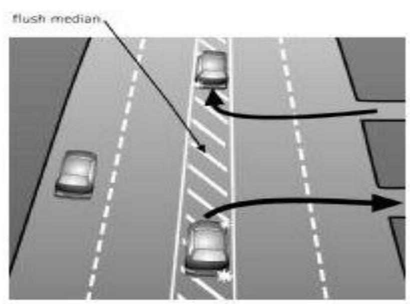
$$e = \frac{4225}{(19050 - 0.15)}$$

$$e = \frac{4225}{(19050 - 0.15)}$$

$$\boldsymbol{e = 0.221}\%$$

16. List any four types of median adopted for highways.

(i) Traversable median
 Flush
(ii) Non transferable median
 Barrier
 Deterring



Flush median

Deterring

Barrier

17. What are the fundamental principles of alignment? (April/May 2019)

a. Short
b. Safe
c. Convenient

18. Elements of Highway cross section

Elements of Highway Cross-section

The elements of geometric design include:

1. Elements of Cross-section
2. Elements of horizontal alignment
3. Elements of vertical alignment

Elements of Cross section

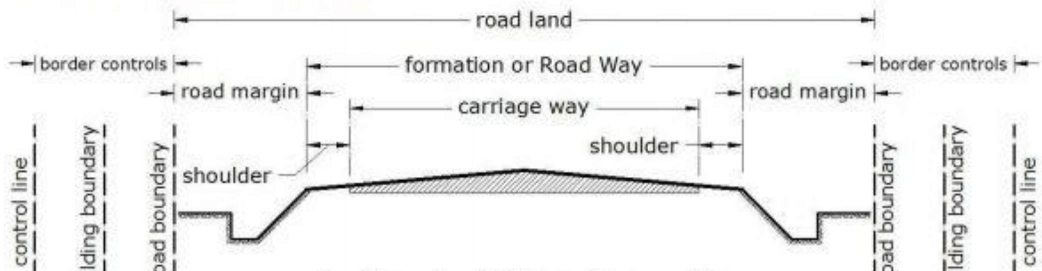


fig: Elements of Highway Cross-section

The main x-sectional elements are:

i) Traffic lane
ii) Carriage way or width of pavement
iii) Shoulder
iv) Road way
v) Width of formation
vi) Side slope of fill or cut
vii) Lay bays
viii) Right of way or land width
ix) Camber
x) Super-elevation

PART-B

1. Describe briefly about gradient and Its types (Nov/Dec 2018)(Nov/Dec 2016)

Gradient

Gradient is the rate of rise or fall along the length of the road with respect to the horizontal. While aligning a highway, the gradient is decided for designing the vertical curve.

The positive gradient or the ascending gradient is denoted as +n and the negative gradient as −n. The deviation angle N is: when two grades meet, the angle which measures the change of direction and is given by the algebraic difference between the two grades $(n_1 - (-n_2)) = n_1 + n_2 = \alpha_1 + \alpha_2$.

Types of gradients

i) Ruling gradient,
ii) Limiting gradient,
iii) Exceptional gradient and
iv) Minimum gradient

(i) Ruling gradient

The ruling gradient or the design gradient is the maximum gradient with which the designer attempts to design the vertical profile of the road. This depends on the terrain, length of the grade, speed, pulling power of the vehicle and the presence of the horizontal curve. In flatter terrain, it may be possible to provide flat gradients, but in hilly terrain it is not economical and sometimes not possible also. The ruling gradient is adopted by the designer by considering a particular speed as the design speed and for a design vehicle with standard dimensions. But our country has a heterogeneous traffic and hence it is not possible to lay down precise standards for the country as a whole. Hence IRC has recommended some values for ruling gradient for different types of terrain.

(ii) Limiting gradient

This gradient is adopted when the ruling gradient results in enormous increase in cost of construction. On rolling terrain and hilly terrain it may be frequently necessary to adopt limiting gradient. But the length of the limiting gradient stretches should be limited and must be sandwiched by either straight roads or easier grades.

(iii) Exceptional gradient

Exceptional gradient are very steeper gradients given at unavoidable situations. They should be limited for short stretches not exceeding about 100 metres at a stretch. In mountainous and steep terrain, successive exceptional gradients must be separated by a minimum 100 metre length gentler gradient. At hairpin bends, the gradient is restricted to

2.5%. Critical length of the grade The maximum length of the ascending gradient which a loaded truck can operate without undue reduction in speed is called critical length of the grade. A speed of 25 kmph is a reasonable value. This value depends on the size, power, load, grad-ability of the truck, initial speed, final desirable minimum speed etc.

(iv) Minimum gradient

This is important only at locations where surface drainage is important. Camber will take care of the lateral drainage. But the longitudinal drainage along the side drains require some slope for smooth flow of water. Therefore minimum gradient is provided for drainage purpose and it depends on the rain fall, type of soil and other site conditions. A minimum of 1 in 500 may be sufficient for concrete drain and 1 in 200 for open soil drains are found to give satisfactory performance.

2. Explain the Factors influencing the geometric design of Hills roads (Nov/Dec 2018)

Design of hill road

a) Rock cutting

The rock stratum slopes downward into the hill side, the rock is permitted to overhang the road forming a half tunnel. Blasting is done either from face or from one or both sides.

The strata are inclined towards the hill slope, cutting is continued until the inner slope is at a safe angle to prevent slipping.

b) Precipice work

Where the time available does not allow for blasting and tunnel work, cliff galleries and cradles are restored for the negotiation of cliffs and precipices. These are suitable only for light vehicles or foot traffic and considered only for short term use and not as a permanent road way for regular traffic. It is an important that the strata should dip inwards from the face in order to ensure safe attachments for the jumpers and holdfasts and to lessen the risk of rock falls.

c) **Retaining walls**

Retaining walls are the most important structure in hill road construction to provide adequate stability to the roadway and to the slope. Retaining walls are constructed on the valley side of the roadway and also on the cut hill side to prevent land slide towards the roadway.

d) Pavement walls

The embankment slopes are normally protected with rough stone pitching about 30cm thick in order to avoid erosion due to flow of water.

If the stopping length is too long it is preferable to construct a toe wall .to support the embankment and depending upon the slope available. Where the cutting slope is steep and contains loose or scour able soils, slips are likely to occur.

e) **Pavement type**

Because of the high intensity of rain fall generally throughout the year in the hill reigns, an important type of pavement proves more effective, through the initial cost may be high. A permeable surface such as W.B.M gets eroded by the heavy rains and regular maintenance cost comes out to be high.

The bituminous pavements are therefore preferred on hill road. Cement concrete pavements are not considered suitable because of its high initial cost and delay in construction

3) Calculate the safe OSD for a design speed of 90 Kmph. Take reaction time of driver as 2.5 seconds and acceleration of overtaking vehicle as 2.5 kmph/sec. Draw OSD Zone. (NOV/Dec 2017)

Given data:
Design speed = 90 kmph
Reaction time = 2.5 sec
Acceleration = 2.5 kmph/sec

Solution

Consider the speed of the overtaking vehicle as the design speed (ie)

V= 90Kmph = 90/ 3.6 = 25 m/ sec
V= v_b=25 m/sec

Acceleration a= 2.5 kmph/sec
OSD= $d_1+d_2+d_3$
Reaction time (t) = 2.5 sec
$d_1= v_b\ t$
= 25x 2.5
= 62.5m

S= [0.7Vb+b]
=[0.7x 25x6]
= 23.5 m

Time T= $\frac{\sqrt{4X\ Vb}}{a}$

$$= \frac{\sqrt{4X\ 25}}{2.5}$$

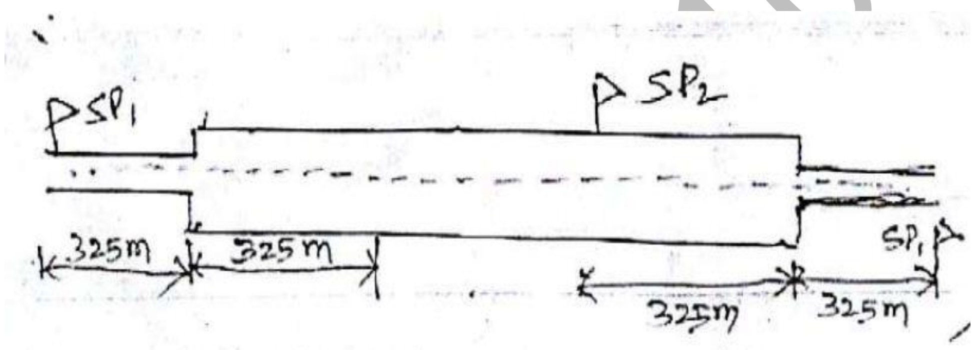
= 6.324 Sec
= 6.3 Sec

d_2 = Vb T+2S

= 25 x 6.3 + 2 x 23.5

= 104.5 m

d_3 = 25x 6.3 = 157.5 m
OSD = 62.5 +104.5 + 157.5
OSD = 62.5 + 104.5 +157.5
OSD = 324.5
OSD =325 m



4 Calculate the length of the transition curve with the following data (Nov/Dec 2017)
Design speeed= 70 kmph, Radius of circular curve = 250 m
Allowable rate of introduction of super elevation =1 in 150.
Pavement width including extrawidth=7.5m

Given data

Design speed =70kmph

Radius of circular curve = 250m

Allowable rate of introduction of super elevation = 1 in 150

Pavement width including extrawidth=7.5m

Solution :

1. **By adopting a particular rate of super elevation length of transition curve**

$$L = \frac{ne}{100}$$

$$L = \frac{300X\ 150}{100}$$

$$L = 450\ m$$

2. **By considering orbitary rate of superelevation**

$$L = \frac{e\ X\ V}{x}$$

$$L = \frac{150\ X\ 70}{2.5}$$

$$L = 4200\ m$$

3. **By considering rate of change of accelaration radius on circular curve**

$$L = \frac{V^2}{R}$$

$$L = \frac{70^2}{250}$$

$$L = 19.6\ m$$

4. **Explain the steps involved in the geometric design of hills roads (April/May 2015)**

Hill road is defined as the one which passes through a terrain with a cross slope of 25% or more. IRC: SP: 73-2015 and IRC: SP: 84-2014 have merged the Mountainous and Steep Terrain having Cross Slope more than 25%.

DESIGN IN HILL ROADS

Design and Construction of Hill roads are more complex than in plain terrain due to factors summarized below:

a) Highly broken relief with vastly differing elevations and steep slopes, deep gorges etc. which increases road length.
b) The geological condition varies from place to place.
c) Variation in hydro-geological conditions.
d) Variation in the climatic condition such as the change in temperature due to altitude difference, pressure variation, precipitation increases at greater height etc.
e) High-speed runoff due to the presence of steep cross slopes.
f) Filling may overload the weak soil underneath which may trigger new slides.
g) Need of design of hairpin bends to attain heights.
h) Need to save Commercial and Residential establishments close to the road.
i) Need to save the ecology of the hills.

SPECIAL CONSIDERATION IN HILL ROAD DESIGN

(i) Alignment of Hill Roads

The designer should attempt to choose a short, easy, economical and safe comforting route.

(ii) General considerations

When designing hill roads the route is located along valleys, hill sides and if required over mountain passes.

Due to complex topography, the length of the route is more.

In locating the alignment special consideration should be made in respect to the variations in:

- Temperature
- Rainfall
- Atmospheric pressure and winds
- Geological conditions
- Resettlement and Rehabilitation considerations
- Environment Considerations

(iii) Temperature

a) Air temperature in the hills is lower than in the valley. The temperature drop being approximately 0.5° per 100 m of rising.

b) On slopes facing south and southwest snow disappears rapidly and rain water evaporates quickly while on slopes facing north and northeast rain water or snow may remain for the longer time.

c) Unequal warming of slopes, sharp temperature variations and erosion by water are the causes of slope failure facing south and southwest.

(iv) Rainfall

a) Rainfall generally increases with increase in height from sea level.

b) The maximum rainfall is in the zone of intensive cloud formation at 1500-2500 m above sea level. Generally, the increase of rainfall for every 100 m of elevation averages 40 to 60 mm.

c) In summer very heavy storms/cloud burst may occur in the hills and about 15 to 25% of the annual rainfall may occur in a single rainfall. The effects of these types of rainfall are serious and should be considered in design.

(v) Atmospheric pressure and winds

- Atmospheric pressure decreases with increase in elevation.
- At high altitudes, the wind velocities may reach up to 25-30 m/s and depth of frost penetration is also 1.5 to 2 m.
- Intensive weathering of rocks because of sharp temperature variations.

(vi) Geological conditions

- The inclination of folds may vary from horizontal to vertical stratification of rock. These folds often have faults. Limestone or sandstone folds may be interleaved with layers of clay which when wetted may cause fracturing along their surface. This may result in shear or slip fold.
- The degree of stability of hill slopes depends on types of rock, degree of strata inclination or dip, occurrence of clay seams, the hardness of the rocks and presence of ground water.
- When locating the route an engineer must study the details of geological conditions of that area and follow stable hill slopes where no ground water, landslides, and unstable folds occur.

(vii) Resettlement and Rehabilitation

- Due to limited availability of flat areas and connectivity issues, most of the residential and commercial activity happens very close to the road leading to large scale R&R and becomes a challenge in alignment design.

(viii) Environment

- Hills are ecologically sensitive areas relatively untouched by human activity. The alignment design must attempt to minimize tree cutting and large scale earth filling/cutting to minimize damage.

(ix) ROUTE SELECTION

Hill road alignment may follow alignment at Valley bottom or on a ridge depending on the feasibility of the road. The first is called **River route** and the second is called **Ridge route.**

a) River route

- Most frequent case of hill alignment as there is a great advantage of running a road at a gentle gradient.
- Runs through lesser horizontal curvature.
- Requirements for the construction of bridges over tributaries.
- Construction of special retaining structures and protection walls on hill side for safe guarding the road against avalanches in high altitude areas.
- Benefit of low construction cost and operation cost.

Ridge route

- Characterized by the very steep gradient.
- Large number of sharp curves occurs on the road with hair pin bends.
- Extensive earthwork is required.
- The requirement for the construction of special structures.
- High construction and operation cost.

GEOMETRIC DESIGN STANDARDS

The various Design Standards being followed in the India for the design of Hill Road are:

IRC:SP:48-1998 **Hill Road Manual.**

IRC:52-2001 **Recommendations About the Alignment Survey and Geometric Design of Hill Roads.**

IRC:SP:91-2010 **Guidelines for Road Tunnels.**

IRC:SP:73-2015 **Manual of Specifications and Standards for Two Laning of Highways with Paved Shoulder.**

IRC:SP:84-2014 **Manual of Specifications and Standards for Four Laning of Highways through Public Private Partnership.**

Hill Road Capacity

Type of Road	Design Service Volume in PCU per day			
	As per IRC:SP:48-1998 and IRC:52- 2001		As per IRC:SP:73-2015 & IRC:SP:84-2014	
	For Low Curvature (0-200 degrees per km)	For High Curvature (above 0-200 degrees per km)	Level of Service 'B'	Level of Service 'C'
Single lane	1,600	1,400	-	-
Intermediate lane	5,200	4,500	-	-
Two Lane	7,000	5,000	9,000	-
Four Lane	-	-	20,000	30,000

Design speed

The design speeds for various categories of hill roads are given below:

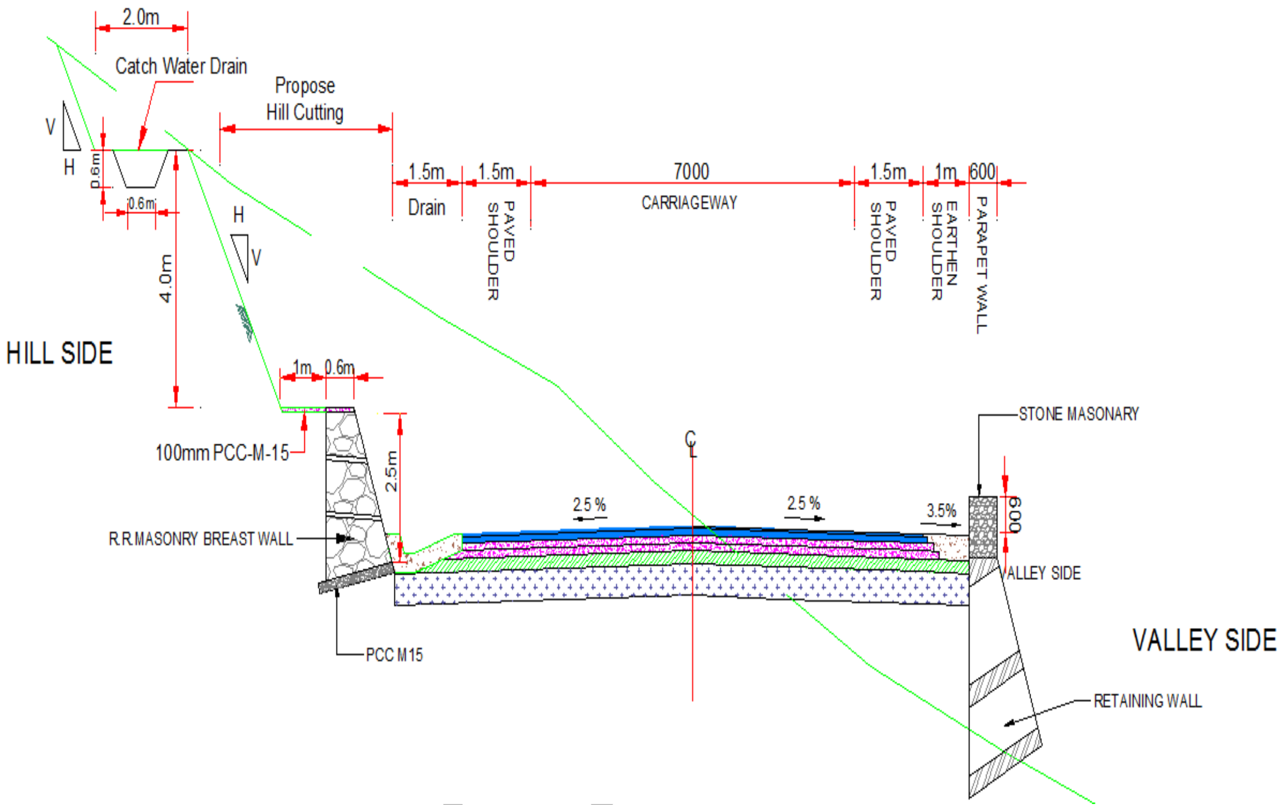
Road Classification	As per IRC:SP:48-1998 and IRC:52-2001				As per IRC:SP:73-2015 & IRC:SP:84-2014	
	Mountainous Terrain		Steep Terrain		Mountainous and Steep Terrain	
	Ruling	Minimum	Ruling	Minimum	Ruling	Minimum
National and State Highways	50	40	40	30	60	40
Major District Roads	40	30	30	20	-	-
Other District Roads	30	25	25	20	-	-
Village Roads	25	20	25	20	-	-

Sight distance

- Visibility is an important requirement for safety on roads.
- It is necessary that sight distance of sufficient length is available to permit drivers enough time and distance to stop their vehicles to avoid accidents.

Design Speed (Km/h)	As per IRC:SP:48-1998 and IRC:52- 2001		As per IRC:SP:73-2015 & IRC:SP:84-2014	
	Mountainous and Steep Terrain			
	Stopping Sight Distance (m)	Intermediate Sight Distance (m)	Safe Stopping Sight Distance (m)	Desirable Minimum Sight Distance (m)
20	20	40	-	-
25	25	50	-	-
30	30	60	-	-
35	40	80	-	-
40	45	90	45	90
50	60	120	60	120
60	-	-	90	180

TYPICAL CROSS-SECTIONS – 2 LANE CARRIAGEWAY
(As per IRC:SP:73-2015)

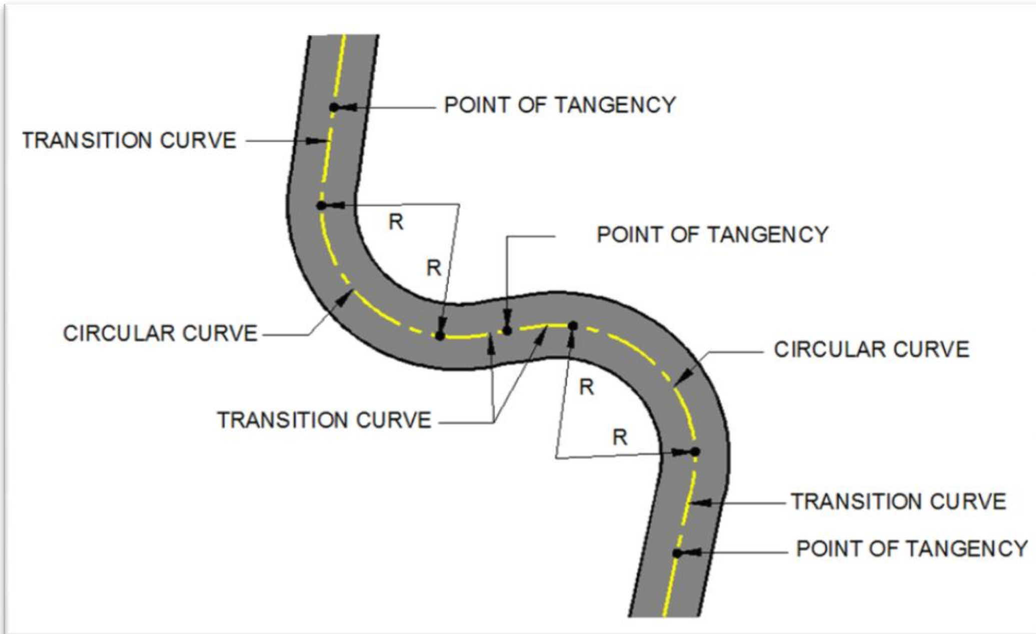


As per IRC:SP:48-1998 and IRC:52- 2001

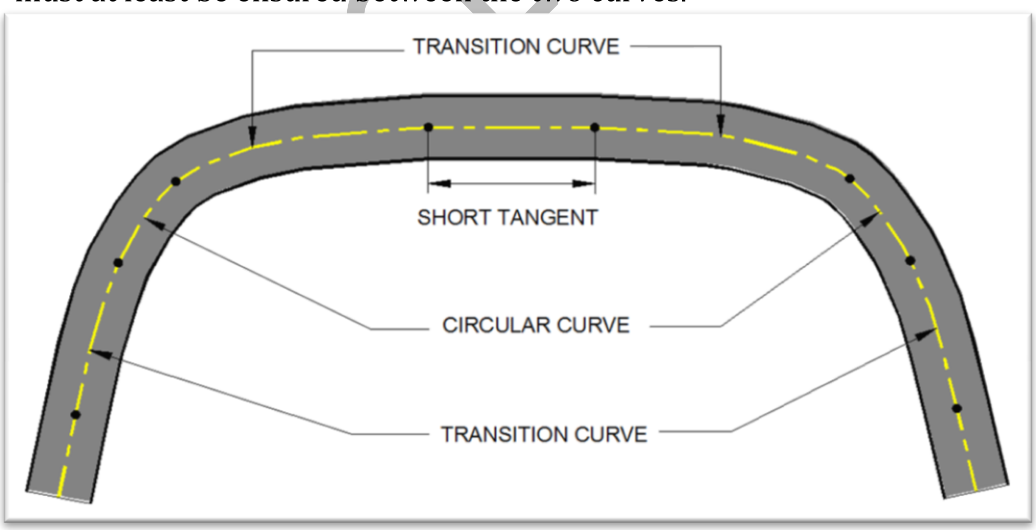
Road Classification	Carriageway Width (m)	Shoulder Width (m)
National and State Highways		
i) Single lane	3.75	2 x 1.25
ii) Double Lane	7.00	2 x 0.9
Major District Roads and Other District Roads	3.75	2 x 0.5
Village Roads	3.00	2 x 0.5

REVERSE CURVES ARE NEEDED IN DIFFICULT TERRAIN.

It should be ensured that there is sufficient length between the two curves for introduction of requisite transition curves.



- Curves in same direction separated by short tangents, known as broken – back curves.
- Should be avoided, as far as possible, in the interest of aesthetics and safety and replaced by a single curve.
- If this is not feasible, a tangent length corresponding to 10 seconds travel time must at least be ensured between the two curves.



Vertical Alignment

- Vertical curves are introduced for smooth transition at grade change.
- Both Summit curves and Valley curves should be designed as Square parabola.
- The Length of vertical curves is controlled by sight distance requirements.
- Curves with greater length are aesthetically better.

Recommended gradients for different terrain conditions, except at hair pin bends, are given below:

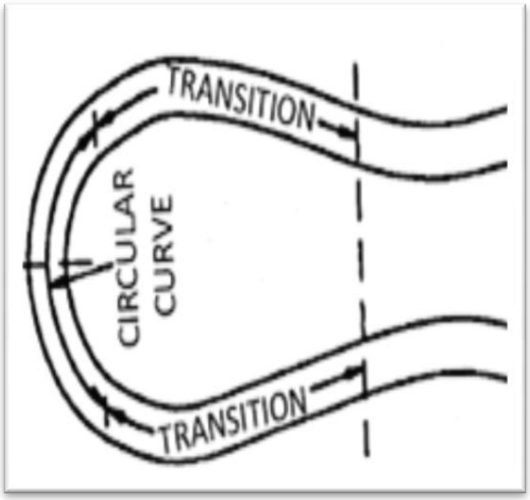
	As per IRC:SP:48-1998 and IRC:52- 2001		As per IRC:SP:73 & IRC:SP:84	
Classification of Gradient	Mountainous Terrain and Steep Terrain more than 3000 m above MSL	Steep Terrain up to 3000 m above MSL	Mountainous	Steep
Ruling Gradient	5%	6%	5%	6%
Limiting Gradient	6%	7%	6%	7%
Exceptional	7%	8%	-	-

At unavoidable circumstances Hair-pin Bends may be designed as Circular Curve with Transitions or as Compound Circular curves.

Design Criteria for Hair-pin Bends as per IRC: SP: 48-1998 and IRC: 52- 2001

Description		Criteria
Min Design Speed		20 Km/h
Min Roadway width at apex	NH/SH	11.5m (Double lane) 9.0m (Single lane)
	MDR/ODR	7.5m
	Village Roads	6.5m
Min radius for the inner curve		14 m
Min Length of transition Curve		15 m
Gradient	Maximum	1 in 40 (2.5%)
	Minimum	1 in 200 (0.5%)
Max Super elevation		1 in 10 (10%)
Minimum Intervening distance between the successive hair pin bends		60m

Illustrations of Hair-pin Bends



5. **Elaborate the factors affecting the geometric design of highways (April/May 2017), (Nov/Dec 2017)**

(Refer Part-B, Question no.4)

6. **Explain the sight distance and types (April/May 2018)**

Types of sight distance Sight distance available from a point is the actual distance along the road surface, over which a driver from a specified height above the carriage way has visibility of stationary or moving objects. Three sight distance situations are considered for design:

i. Stopping sight distance (SSD) or the absolute minimum sight distance
ii. Intermediate sight distance (ISD) is defined as twice SSD
iii. Overtaking sight distance (OSD) for safe overtaking operation
iv. Head light sight distance is the distance visible to a driver during night driving under the illumination of head lights
v. Safe sight distance to enter into an intersection.

The most important consideration in all these is that at all times the driver traveling at the design speed of the highway must have sufficient carriageway distance within his line of vision to allow him to stop his vehicle before colliding with a slowly moving or stationary object appearing suddenly in his own traffic lane. The computation of sight distance depends on:

Reaction time of the driver

Reaction time of a driver is the time taken from the instant the object is visible to the driver to the instant when the brakes are applied. The total reaction time may be split up into four components based on PIEV theory. In practice, all these times are usually combined into a total perception-reaction time suitable for design purposes as well as for easy measurement. Many of the studies shows that drivers require about 1.5 to 2 secs under normal conditions. However, taking into consideration the variability of driver characteristics, a higher value is normally used in design. For example, IRC suggests a reaction time of 2.5 secs.

Speed of the vehicle

The speed of the vehicle very much affects the sight distance. Higher the speed, more time will be required to stop the vehicle. Hence it is evident that, as the speed increases, sight distance also increases.

Efficiency of brakes

The efficiency of the brakes depends upon the age of the vehicle, vehicle characteristics etc. If the brake efficiency is 100%, the vehicle will stop the moment the brakes are applied. But practically, it is not possible to achieve 100% brake efficiency. Therefore the sight distance required will be more when the efficiency of brakes are less. Also for safe geometric design, we assume that the vehicles have only 50% brake efficiency.

Frictional resistance between the tyre and the road

The frictional resistance between the tyre and road plays an important role to bring the vehicle to stop. When the frictional resistance is more, the vehicles stop immediately. Thus sight required will be less. No separate provision for brake efficiency is provided while computing the sight distance. This is taken into account along with the factor of longitudinal friction. IRC has specified the value of longitudinal friction in between 0.35 to 0.4.

Gradient of the road.

Gradient of the road also affects the sight distance. While climbing up a gradient, the vehicle can stop immediately. Therefore sight distance required is less. While descending a gradient, gravity also comes into action and more time will be required to stop the vehicle. Sight distance required will be more in this case.

Stopping sight distance

Stopping sight distance (SSD) is the minimum sight distance available on a highway at any spot having sufficient length to enable the driver to stop a vehicle traveling at design speed, safely without collision with any other obstruction. There is a term called safe stopping distance and is one of the important measures in traffic engineering. It is the distance a vehicle travels from the point at which a situation is first perceived to the time the deceleration is complete. Drivers must have adequate time if they are to suddenly respond to a situation. Thus in highway design, sight distance atleast equal to the safe stopping distance should be provided.

The stopping sight distance is the sum of lag distance and the braking distance. Lag distance is the distance the vehicle traveled during the reaction time t and is given by vt, where v is the velocity in m/sec^2 .

Braking distance is the distance traveled by the vehicle during braking operation. For a level road this is obtained by equating the work done in stopping the vehicle and the kinetic energy of the vehicle.

If F is the maximum frictional force developed and the braking distance is l, then work done against friction in stopping the vehicle is Fl = fWl where W is the total weight of the vehicle. The kinetic energy at the design speed is

$$\frac{1}{2}mv^2 = \frac{1}{2}\frac{Wv^2}{g}$$

$$fWl = \frac{Wv^2}{2g}$$

$$l = \frac{v^2}{2gf}$$

Therefore, the SSD = lag distance + braking distance and given by:

$$SSD = vt + \frac{v^2}{2gf}$$

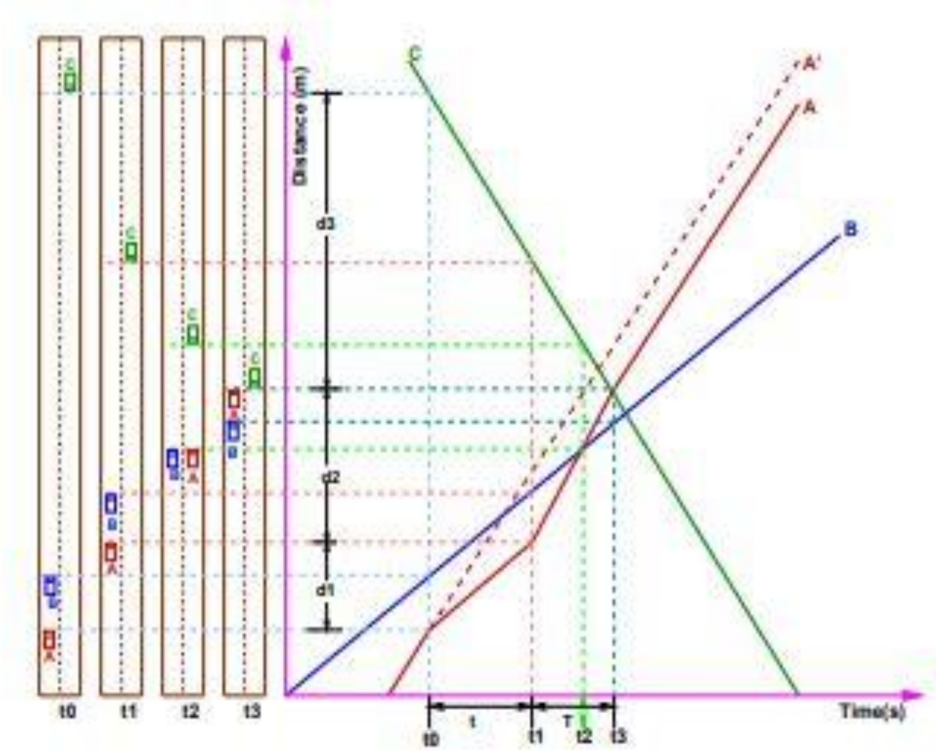
Similarly the braking distance can be derived for a descending gradient. Therefore the general equation is given by Equation

$$SSD = vt + \frac{v^2}{2g(f \pm 0.01n)}$$

Overtaking sight distance

The overtaking sight distance is the minimum distance open to the vision of the driver of a vehicle intending to overtake the slow vehicle ahead safely against the traffic in the opposite direction. The overtaking sight distance or passing sight distance is measured along the center line of the road over which a driver with his eye level 1.2 m above the road surface can see the top of an object 1.2 m above the road surface. The factors that affect the OSD are:

- Velocities of the overtaking vehicle, overtaken vehicle and of the vehicle coming in the opposite direction.
- Spacing between vehicles, which in-turn depends on the speed
- Skill and reaction time of the driver
- Rate of acceleration of overtaking vehicle
- Gradient of the road



Time-space diagram: Illustration of overtaking sight distance

The dynamics of the overtaking operation is given in the figure which is a time-space diagram. The x-axis denotes the time and y-axis shows the distance traveled by the vehicles. The trajectory of the slow moving vehicle (B) is shown as a straight line which indicates that it is traveling at a constant speed. A fast moving vehicle (A) is traveling behind the vehicle B.

The trajectory of the vehicle is shown initially with a steeper slope. The dotted line indicates the path of the vehicle A if B was absent. The vehicle A slows down to follow the vehicle B as shown in the figure with same slope from t_0 to t_1. Then it overtakes the vehicle B and occupies the left lane at time t_3. The time duration $T = t_3 - t_1$ is the actual duration of the overtaking operation. The snapshots of the road at time t_0, t_1, and t_3 are shown on the left side of the figure.

From the the overtaking sight distance consists of three parts.

d_1 the distance traveled by overtaking vehicle A during the reaction time $t = t_1 - t_0$

d_2 the distance traveled by the vehicle during the actual overtaking operation $T = t_3 - t_1$

d_3 is the distance traveled by on-coming vehicle C during the overtaking operation (T).

Therefore:

$$OSD = d_1 + d_2 + d_3$$

It is assumed that the vehicle A is forced to reduce its speed to vb, the speed of the slow moving vehicle B and travels behind it during the reaction time t of the driver. So d_1 is given by:

$$d_1 = v_b t$$

Then the vehicle A starts to accelerate, shifts the lane, overtake and shift back to the original lane. The vehicle A maintains the spacing s before and after overtaking. The spacing s in m is given by:

$$s = 0.7v_b + 6$$

Let T be the duration of actual overtaking. The distance traveled by B during the overtaking operation is 2s+vbT. Also, during this time, vehicle A accelerated from initial velocity vb and overtaking is completed while reaching final velocity v. Hence the distance traveled is given by:

$$\begin{aligned}
d_2 &= v_b T + \frac{1}{2}aT^2 \\
2s + v_b T &= v_b T + \frac{1}{2}aT^2 \\
2s &= \frac{1}{2}aT^2 \\
T &= \sqrt{\frac{4s}{a}} \\
d_2 &= 2s + v_b\sqrt{\frac{4s}{a}}
\end{aligned}$$

The distance traveled by the vehicle C moving at design speed v m/sec during overtaking operation is given by: d3 = vT

$$OSD = v_b t + 2s + v_b \sqrt{\frac{4s}{a}} + vT$$

where vb is the velocity of the slow moving vehicle in m/se^{c2} , t the reaction time of the driver in sec, s is the spacing between the two vehicle in m given by equation 13.5 and a is the overtaking vehicles acceleration in m/sec^2 . In case the speed of the overtaken vehicle is not given, it can be assumed that it moves 16 kmph slower the design speed. On divided highways, d_3 need not be considered

On divided highways with four or more lanes, IRC suggests that it is not necessary to provide the OSD, but only SSD is sufficient.

7. The speed of overtaking and overtaken vehicles is 80 and 50 kmph respectively. On a two way traffic load, the acceleration of overtaking vehicles is 0.99 m/sec^2 . Calculate OSD, mention the minimum length of overtaking zone and draw sketch of the overtaking zone with all details. (April/May 2017)

Solution

Given data:

Speed of overtaking vehicle, V = 70 kmph, therefore v = 70/3.6 = 19.4 m/sec

Speed of overtaken vehicle, V_b = 40 kmph, therefore v_b = 40/3.6 = 11.1 m/sec

Average acceleration during overtaking, a = 0.99 m/sec^2

(a) Overtaking sight distance for two way traffic, vide Eq 4.7, OSD $= (d_1 + d_2 + d_3) = (v_b\, t + v_b\, T + 2s + vT)$ m

Reaction time for overtaking, t = 2 sec

$d_1 = v_b\, t = 11.1 \times 2 = 22.2$ m

$d_2 = v_b\, T + 2\, s$

$s = (0.7\, v_b + 6) = (0.7 \times 11.1 + 6) = 13.8$ m

$$T = \sqrt{\frac{4s}{a}} = \sqrt{\frac{4 \times 13.8}{0.99}} = 7.47 \text{ sec}$$

$d_2 = 11.1 \times 7.47 + 2 \times 13.8 = 110.5$ m

$d_3 = v\,T = 19.4 \times 7.47 = 144.9$ m

OSD $= d_1 + d_2 + d_3 = 22.2 + 110.5 + 144.9 = 277.6$ m, say 278 m

(b) Minimum length of overtaking zone = 3 (OSD) = 3 × 278 = 834 m

Desirable length of overtaking zone = 5 × (OSD) = 5 × 278 = 1390

(c) The details of the overtaking zone are shown in Fig. 4.16

8. **(i) List and draw the various vertical curves adopted in highways.**
(ii) Explain the controls and guidelines for safe, comfortable travel in highway vertical curves.
(iii) List the various technical guidelines recommended for safety and comfort in case of horizontal curves in highways.

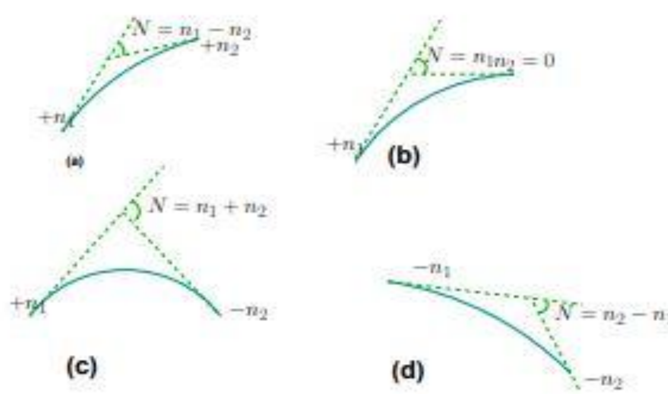
(i) SUMMIT CURVE

Summit curves are vertical curves with gradient upwards.

They are formed when two gradients meet as illustrated in figure 1 in any of the following four ways:

1. When a positive gradient meets another positive gradient [figure 1a]
2. When positive gradient meets a flat gradient [figure 1b].
3. When an ascending gradient meets a descending gradient [figure 1c]
4. When a descending gradient meets another descending gradient [figure 1d]

Type of Summit Curve Many curve forms can be used with satisfactory results, the common practice has been to use parabolic curves in summit curves. This is primarily because of the ease with it can be laid out as well as allowing a comfortable transition from one gradient to another. Although a circular curve offers equal sight distance at every point on the curve, for very small deviation angles a circular curve and parabolic curves are almost congruent. Furthermore, the use of parabolic curves were found to give excellent riding comfort.



(ii) Design Consideration

In determining the type and length of the vertical curve, the design considerations are comfort and security of the driver, and the appearance of the profile alignment. Among these, sight distance requirements for the safety are most important on summit curves.

The stopping sight distance or absolute minimum sight distance should be provided on these curves and where overtaking is not prohibited, overtaking sight distance or intermediate sight distance should be provided as far as possible.

When a fast moving vehicle travels along a summit curve, there is less discomfort to the passengers. This is because the centrifugal force will be acting upwards while the vehicle negotiates a summit curve which is against the gravity and hence a part of the tyre pressure is relieved.

Also if the curve is provided with adequate sight distance, the length would be sufficient to ease the shock due to change in gradient. Circular summit curves are identical since the radius remains same throughout and hence the sight distance.

From this point of view, transition curves are not desirable since it has varying radius and so the sight distance will also vary. The deviation angles provided on summit curves for highways are very large, and so the simple parabola is almost congruent to a circular arc, between the same tangent points.

Parabolic curves are easy for computation and also it had been found out that it provides good riding comfort to the drivers. It is also easy for field implementation. Due to all these reasons, a simple parabolic curve is preferred as summit curve.

9. **(i) Calculate the super-elevation to be provided for a horizontal curve with a radius of 400 m for a design speed 100 kmph in plain terrain. If super-elevation is restricted to 0.07, calculate the coefficient of lateral friction mobilized.**
   (ii) Calculate the safe stopping distance while travelling at a speed of 100 kmph on a level road.

   (iii) Draw the various components of overtaking sight distance on a straight stretch of a highway and explain each one. (Nov/Dec 2015)

Solution

Given data:

Speed of overtaking vehicle, V = 70 kmph, therefore $v = 70/3.6 = 19.4$ m/sec

Speed of overtaken vehicle, V_b = 40 kmph, therefore $v_b = 40/3.6 = 11.1$ m/sec

Average acceleration during overtaking, $a = 0.99$ m/sec^2

(a) Overtaking sight distance for two way traffic, vide Eq 4.7, OSD

$= (d_1 + d_2 + d_3) = (v_b t + v_b T + 2s + vT)$ m

Reaction time for overtaking, t = 2 sec

$$d_1 = v_b t = 11.1 \times 2 = 22.2 \text{ m}$$

$$d_2 = v_b T + 2s$$

$$s = (0.7 v_b + 6) = (0.7 \times 11.1 + 6) = 13.8 \text{ m}$$

$$T = \sqrt{\frac{4s}{a}} = \sqrt{\frac{4 \times 13.8}{0.99}} = 7.47 \text{ sec}$$

$$d_2 = 11.1 \times 7.47 + 2 \times 13.8 = 110.5 \text{ m}$$

$$d_3 = vT = 19.4 \times 7.47 = 144.9 \text{ m}$$

$$OSD = d_1 + d_2 + d_3 = 22.2 + 110.5 + 144.9 = 277.6 \text{ m, say } 278 \text{ m}$$

(b) Minimum length of overtaking zone = 3 (OSD) = 3 × 278 = 834 m

Desirable length of overtaking zone = 5 × (OSD) = 5 × 278 = 1390

(c) The details of the overtaking zone are shown in Fig. 4.16

10. Find the rate of super elevation on a horizontal curve having a radius curvature of 90m. The design speed is 50Kmph and assume f= 0.15. (Nov/Dec 2017)

Solution:

$$\boxed{\therefore e + f = \frac{V^2}{127R}}$$

$$e + 0.15 = \frac{(50)^2}{127(90)}$$

$$e = \frac{2500}{(11430 - 0.15)}$$

$$e = \frac{2500}{(11429)}$$

$$\boldsymbol{e = 0.218}$$

11. Explain shortly various special considerations to be given in design and construction of Hilly roads in highway design. (Nov/Dec 2018)

(Refer Question no.4 in Part B)

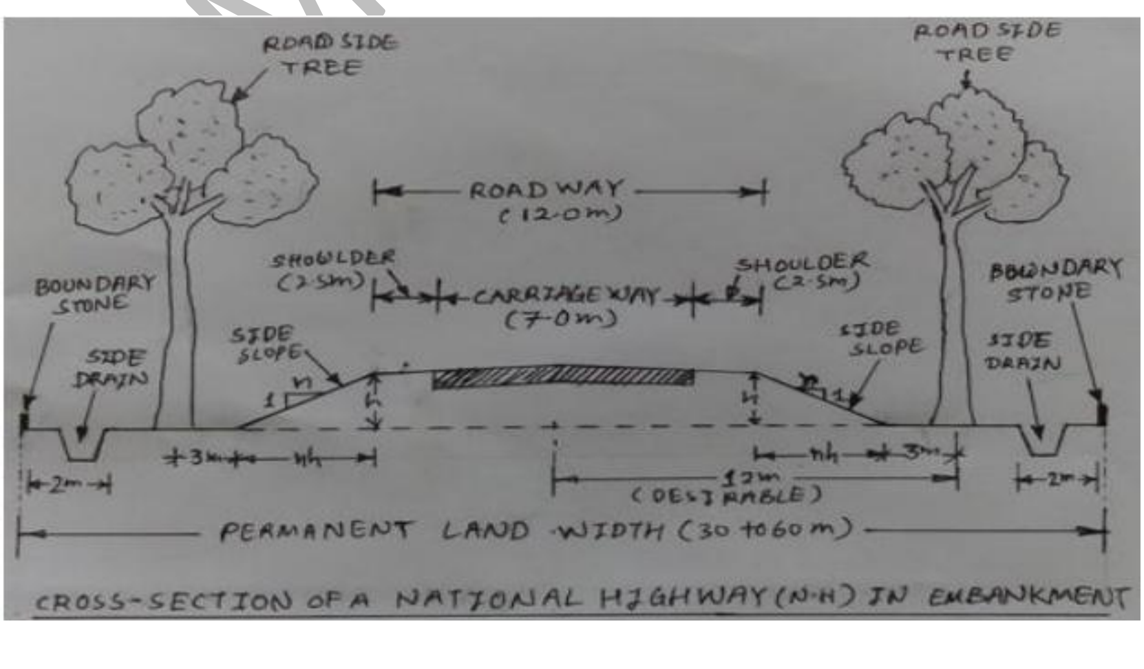
12. Explain in brief the various classifications rural roads with its salient components as per IRC Standards with neat sketches.(Nov/Dec 2018)

The Indian Highways as classified in types of roads are as follows.

(i) National Highways (NH)
(ii) State Highways (SH)
(iii) Major District Roads (MDR)
(iv) Other District Highways (ODR)
(v) Village Roads (VR)

(i) National highways

National highways are the main highways running through the length and breath of India, connecting major parts, highways, capital of large states and industrial and tourist centers including roads required for strategic movements for the defense of India. It was agreed that a first step national trails should be constructed by the centre and that latter's these should be converted into roads to suit the traffic conditions.



CROSS-SECTION OF A NATIONAL HIGHWAY (N-H) IN EMBANKMENT

It was specified that national highways should be the frame on which the entire road communication should be based on that these highways may not necessarily be of same specification, but they must give an uninterrupted road communication through India and should connect the entire road network.

(ii) State highways

State highways are the arterial roads of a state, connecting up with the national highways of adjacent state, district headquarters and important cities within the state and serving as the main arteries for traffic to and from district roads.

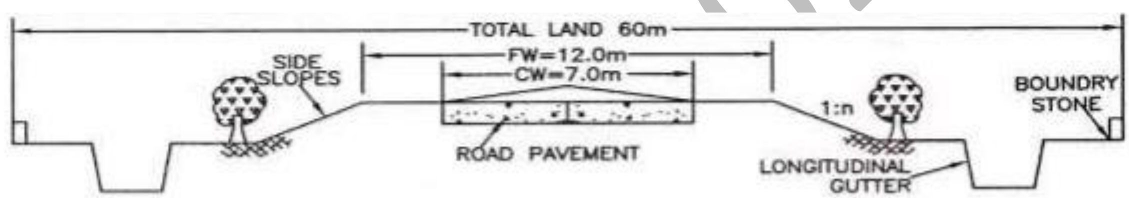


FIG. 3.4 CROSS-SECTION OF NH OR SH IN RURAL AREA IN EMBANKMENT

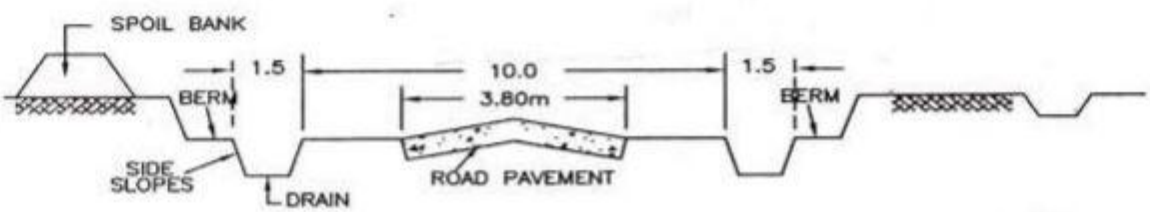


FIG. 3.5 CROSS-SECTION OF MDR IN CUTTING IN RURAL AREA

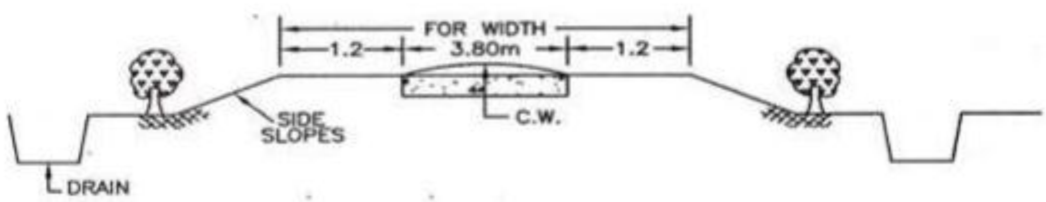
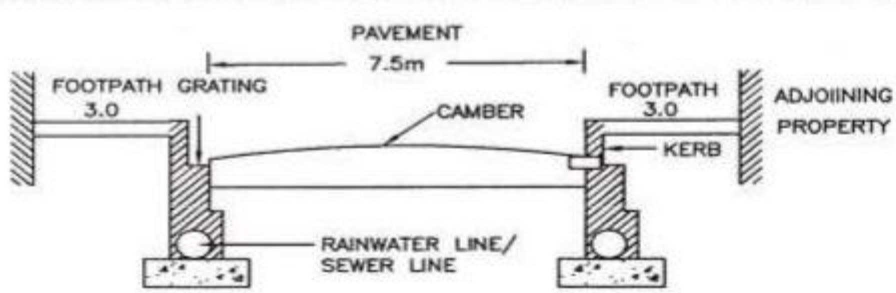


FIG. 3.6 CROSS-SECTION OF VR OR ODR IN EMBANKMENT IN RURAL AREA



These highways are considered as main arteries of commerce by roads within a state or a similar geographical unit. In some places they may be even carry heavier traffic than some of the national highways but this will not alter their designation or function. The NH and SH have some design speed and geometric design specification.

(iii) Major district roads

Major district roads are the important roads within a district serving areas of production and markets and providing them with outlet to markets and connecting those with each other or with the main highways of a district. the MDR has lower speed and geometric design specifications than NH/SH.

(iv) Other district roads

Other district roads are roads serving rural areas of production and providing them with outlet to market Centre's taluk headquarters block development headquarters or other main roads. These are of lower design specifications then MDR.

(v) Village roads

Village roads are road connecting villages or groups of villages with each other to the nearest road of a higher category. It was specified that these villages roads should be in essence farm tracks, but it was desired that the prevalent practice of leaving such tracks to develop and maintain by themselves should be replaced by a plan for a designed and regulated system.

The Each type of roads from Expressway , National Highways (NH), State Highways (SH), Major District Roads (MDR), Other District Highways (ODR), Village Roads (VR , briefly presented its specifications in below the table.

Specifications	**Expressway**	**National Highways**	**State Highways**	**Major District Roads**	**Other District Roads**	**Village Roads**
Right of way	90-100m	45m	45m	25m	15m	12m
Carriage way	11.25m	12m	12m	9m	7.5m	7.5m
Speed	120 km/hr	100 km/hr	80 km/hr	60 km/hr	50 km/hr	40 km/hr
Horizontal curve	700-2600m	360m	360m	230m	155m	90m
Vertical curve (Minimum)	0.5 %	0.6 %	0.8 %	1.0 %	1.2 %	1.5 %
Camber	2.5%	2.5 %	2.5 %	2.5 %	2.5 %	2.5 %
Median	12-15m	4m	2m	1m	0.5m	Nil
Shoulder	2.5-3.0 m	2.5m	1m	0.5m	0.5m	Unpaved
Super elevation	7%	7%	7%	7%	7%	7%

13. **A road has a total width of 7.5 m including extra widening on curve and design speed of 65kmph. Calculate the length of transition curve and its shift on this curve of 200m radius. Allowable super elevation is 1 in 150 and pavement is rotated about centre line. (Nov/Dec 2019), (Nov/Dec 2016)**

Solution:

Design speed	= 65kmph
Radius of curve	= 200 m
Total pavement width	= 7.5 m (Including Extra Widening)
Rate of Super elevation	= 1 in 150

A) <u>Length of transition curve, (Ls)</u>

Length based allowable rate of centrifugal acceleration, C

$$C = \frac{80}{75+V}$$

$$C = \frac{80}{75+65} = 0.57 \ \ m/sec^3$$

As the value of C is between 0.5 and 0.8, C= 0.57 is accepted

$$Ls = \frac{0.0215V^3}{CR}$$

$$Ls = \frac{0.0215(65^3)}{0.57x200} = \frac{5904.437}{114} = \mathbf{51.79\ m}$$

Length by allowable rate of introduction of super elevation, E

Super elevation rate $\boldsymbol{e} = \frac{\mathbf{V^2}}{\mathbf{225R}} = \frac{\mathbf{65^2}}{\mathbf{225x200}}$

$$\mathbf{e} = \frac{\mathbf{65^2}}{\mathbf{225x200}} = 0.080$$

As this value is greater than the maximum allowable rate of 0.07, limit the value of e=0.07. Check the safety against traverse skidding by finding the friction co efficient developed, fd for the design speed of 65 kmph.

$$fd = \frac{V^2}{225R} - e$$

$$fd = \frac{65^2}{225 \text{x} 200} - 0.07$$

$$fd = 0.0938 - 0.07 = 0.023$$

Total width of the pavement at the curve, B=7.5 m

Total raise of outer edge of pavement with respect to the centre line

$$= \frac{E}{2} = \frac{eB}{2} = \frac{0.07x7.5}{2} = 0.26\ m$$

Rate of super elevation, 1 in N=1 in 150

$$Ls = \frac{EN}{2} = 0.26\ x\ 150 = 39\ m$$

Length as per IRC empirical formula

$$= \frac{\mathbf{2.7\ V^2}}{\mathbf{R}} = \frac{\mathbf{2.7\ x\ 65^2}}{\mathbf{200}} = \frac{11407.5}{200} = 57.03 \text{ m}$$

Adopt the highest value 57 m as the design length of transition curve

B) <u>Shift of transition curve, (Ls)</u>

$$\boldsymbol{S = \frac{Ls^2}{24R} = \frac{57^2}{24\ x\ 200} = \frac{3249}{4800} = 0.67\text{m}}$$